NBSIR 84-2937

Validation of Daylight Prediction With CEL-1

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

FOREWORD

This report documents the results of National Bureau of Standards (NBS) research in support of the Naval Civil Engineering Laboratory. The report summarizes work conducted during the period January 1983 through January 1984.

We wish to acknowledge the helpful interest and guidance of the sponsor's Project Officer, Mr. William Pierpoint.

DISCLAIMER

ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of all those who participated in this project and who provided insightful comments during the review process.

ABSTRACT

Calculations of interior illuminance levels using the CEL-1 computer program are compared to measurements, for a typical office space. The comparisons are made for a wide range of sky conditions, solar intensities and seasonal intervals using a north facing window. The statistical uncertainty associated with the interior daylight calculations is examined and the sources of the uncertainty are discussed. The results show that for all sky types, the interior illuminance calculations have an uncertainty of +/-24%, with the major uncertainties being due to unique and unpredictable sky luminance distributions and difficulty in determining the appropriate sky condition from standard weather data.

Keywords: building energy, daylight, illuminance, fenestration, solar radiation, window

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1. INTRODUCTION

Electrical energy for interior lighting is a significant portion of building total energy requirements, and also a large component of the cooling load [1,2,3]. Many studies have shown that the effective use of fenestration to provide daylight for interior spaces can be beneficial in reducing annual total building energy requirements by reducing both lighting and cooling energy use [4,5,6,7,8].

When a building is being designed, the solar, thermal and daylighting impacts of various fenestration designs must be evaluated to determine the net energy impact of each design. In this manner, the optimum design may be determined and specified. The evaluation can consist of the application of various design procedures and guidelines, ranging from hand calculation procedures, to design nomographs, to detailed computer simulations. One of the critical aspects of any evaluation of fenestration performance is the prediction of interior illuminance levels due to daylight. Such a prediction is needed in order to determine the level of electric lighting required to maintain the desired interior illuminance. Additional calculations are required to determine the electric power required by the lighting system to provide the difference between the daylight illumination and the minimum desired illuminance level.

The purpose of this report is to validate the interior daylight prediction portion of the CEL-1 Lighting Computer Program. This program was developed by the Naval Civil Engineering Laboratory and possesses the capabilities to calculate interior illuminance for all sky types and to model actual lighting systems, including luminaires and dimming controls. Comparison data for the validation were obtained from measurements at the NBS Daylight Research Facility, using a full-size test room with a north-facing, unobstructed window. The test room was modeled and daylight levels calculated using CEL-1 and the results compared to the measured illuminance levels for a variety of sky conditions.

2. THE CEL-1 LIGHTING COMPUTER PROGRAM

The test room was modeled using the CEL-1 computer simulation procedure. Details of developing a CEL-1 input file and executing the program can be found in other publications [9,10]. Basically, the test room layout, dimensions, and surface reflectances are modeled, and weather data is used to generate a model of sky and solar illuminace. Flux exchange calculations then are used, after each room surface is subdivided into small surfaces, to determine interior illuminance at the point of interest.

In its normal mode of operation, CEL-1 reads solar radiation data, direct and diffuse, from a weather tape. This irradiance data is translated into illuminance data which, along with the current solar angles, are required for the interior illuminance calculations. For the validation, the measured irradiance levels were used to drive the CEL-1 predictions, so that the predictions could be compared to the measured illuminance levels.

The CEL-1 input file listing is given in Table 1.

Table 1

CEL-1 Input File Listing

```
ROOM
CEL-1 TEST RUN
ANALYSIS MODE WITH MODIFICATIONS
WEATHER DATA INPUT
JULIAN DATES PROCESSED:    91,189,349
************************************************
  1 2
   5 20   5   11.20 11    6.90   6
  .470   .470   .470   .470   .300   .850
TASK
KNOWN
  4   2.50
    2.00    2.80     0.0
    3.60    2.80     0.0
    2.00    7.40     0.0
    3.60    7.40     0.0
SENSORS
  1
    2 60     5.60     2.50   6
  0
FENESTRATION
WINDOW
  1   .800
    5.20    2.80
  1
 2    0.00   11.20    3.10
BUILDING
  1
    -1.0     -1.0     -1.0        7.2      13.2       8.9
  .600   .600   .600   .600   .200
    0.0
GROUND
  .200
  0
ANALYSIS
   38 50    77.00    75.00   53
  0 0 0 0 1 1 1 1 1 1 0 0
  15
  4  1 7.30
  4  1 9.30
  4  1 11.30
  4  1 13.30
  4  1 15.30
  7 8 7.29
  7 8 9.29
  7 8 11.29
  7 8 13.29
  7 8 15.29
  12 15 7.46
  12 15 9.46
  12 15 11.46
  12 15 13.46
  12 15 15.46
CALCULATE
HOR
P25B
P25T
---
```

3. DESCRIPTION OF THE MEASUREMENTS

Interior daylight illuminance was measured in a rectangular test room with a north-facing window. A schematic drawing of the test room is shown in Figure 1. Illuminance on a horizontal plane was measured in the center of the room at a height of 76cm (2.5ft). The view out of the window from this point was nearly unobstructed, except for a few tree tops which obscured less than 10 percent of the sky view. Illuminance was measured using silicon photovoltaic cells with cosine diffusers and photometric filters. Concurrent measurements of solar radiation and illumination levels were made for both diffuse (sky) and global (sky and sun) components, to provide the input data necessary for the CEL-1 simulations. Data were collected over a six-month period to enable validation for a wide range of sky, solar and seasonal conditions. A complete description of test room dimensions and reflectances and window parameters is given in Table 2.

Table 2

Test Room Dimensions and Reflectances

Test Room		
Width	1.6m	(5.2 ft)
Height	2.1m	(6.9 ft)
Depth	3.4m	(11.2 ft)
Reflectances		
Wall	0.47	
Floor	0.30	
Ceiling	0.85	
Window - Double Pane		
Width	1.6m	(5.2 ft)
Height	0.9m	(2.8 ft)
Visible Transmittance	0.80	

4. RESULTS

The validation results are presented in two formats. Figures 2 thru 6 each present a comparison of predicted versus measured illuminances for each of five days. In these figures, calculated interior illuminances are plotted for each sky type, and the calculated illuminances for the sky types as chosen by CEL-1 are circled, and labeled with the atmospheric extinction coefficient as determined from measurement. Calculations were made for five times each day. Each measured interior illuminance consisted of a one-hour average, so the calculation used similarily averaged solar data. These five days include clear, partly cloudy, and overcast sky types from different times of the year. The days were chosen at random. From these figures it is seen that the CEL-1 predictions tend to follow the measured values closely, although some deviations are clearly evident. Figure 7 presents an overall comparison between the measurements and predictions.

A simple calculation of the standard deviation of the numbers formed by taking the ratio's of the CEL-1 predicted values to the corresponding measured values (or, alternatively, of the root-mean-square deviation of the ratio's from the constant model (unity) gives a 24% value. This can be thought of as representing a typical error of prediction. Expression in percent terms is preferred since the width of the error band clearly must increase with the magnitude of the prediction.

The levels of uncertainty described above are similar to the uncertainties stated for other similar illuminance prediction procedures, although validations of this type are rarely attempted. Most of the uncertainty is due to the random nature of real skies, which are rarely uniformly or predictably overcast or clear. Since any one window sees only a small portion of the sky, small variations in the luminance distribution of that portion of the sky can have a strong impact on interior illuminance, variations which would be too subtle for a computer model to predict using horizontal solar radiation as a driving function. This effect is illustrated in Figure 8, which presents a hemispherical photograph of a partly cloudy sky. From this figure it is obvious that daylight illumination due to the sky as seen through window A would be significantly greater than that through window B, although both windows have nearly the same orientation.

Another uncertainty source is the determination of sky type. CEL-1 determines sky type on the basis of atmospheric extinction coefficient which is calculated from the level of direct beam illuminance. Thus, if no significant direct beam irradiance is incident, the sky is assumed to be overcast, and high direct beam irradiances are assumed to mean clear skies. These two assumptions are usually, but not always, valid. A single cloud could completely extinguish the direct beam solar radiation incident upon a surface, while the rest of the sky remained clear, or the sky could be nearly overcast except in front of the sun. Partly cloudy skies are particularly difficult to predict, due to their wide dynamic range.

Taking into consideration the uncertainty associated with predicting interior daylight levels, it is still of value to use such techniques for evaluating fenestration performance. While one hundred percent accuracy is not possible, it is possible to compare the relative performance of various fenestration options as long as they are compared on a fair and equal basis.

Thus, it is most important that the simulation be realistic and reasonable even though the probabalistic aspects of sky modeling cannot be completely addressed. The validation figures demonstrate that the CEL-1 daylight illuminance predictions are reasonable for typical office spaces and realistic for the purpose of comparing fenestration options.

5. CONCLUSIONS

Comparisons of predicted and measured interior illuminance levels were performed using the CEL-1 Lighting Computer Program and measurements made at the NBS Daylight Research Facility. Results of the validation indicate a prediction uncertainty of +/- 24%, an uncertainty level which is expected for this type of validation. The major sources of uncertainty are believed to be associated with random and unpredictable cloud patterns. It is concluded that the CEL-1 simulation procedure would be of value in evaluating the daylighting performance of fenestration systems.

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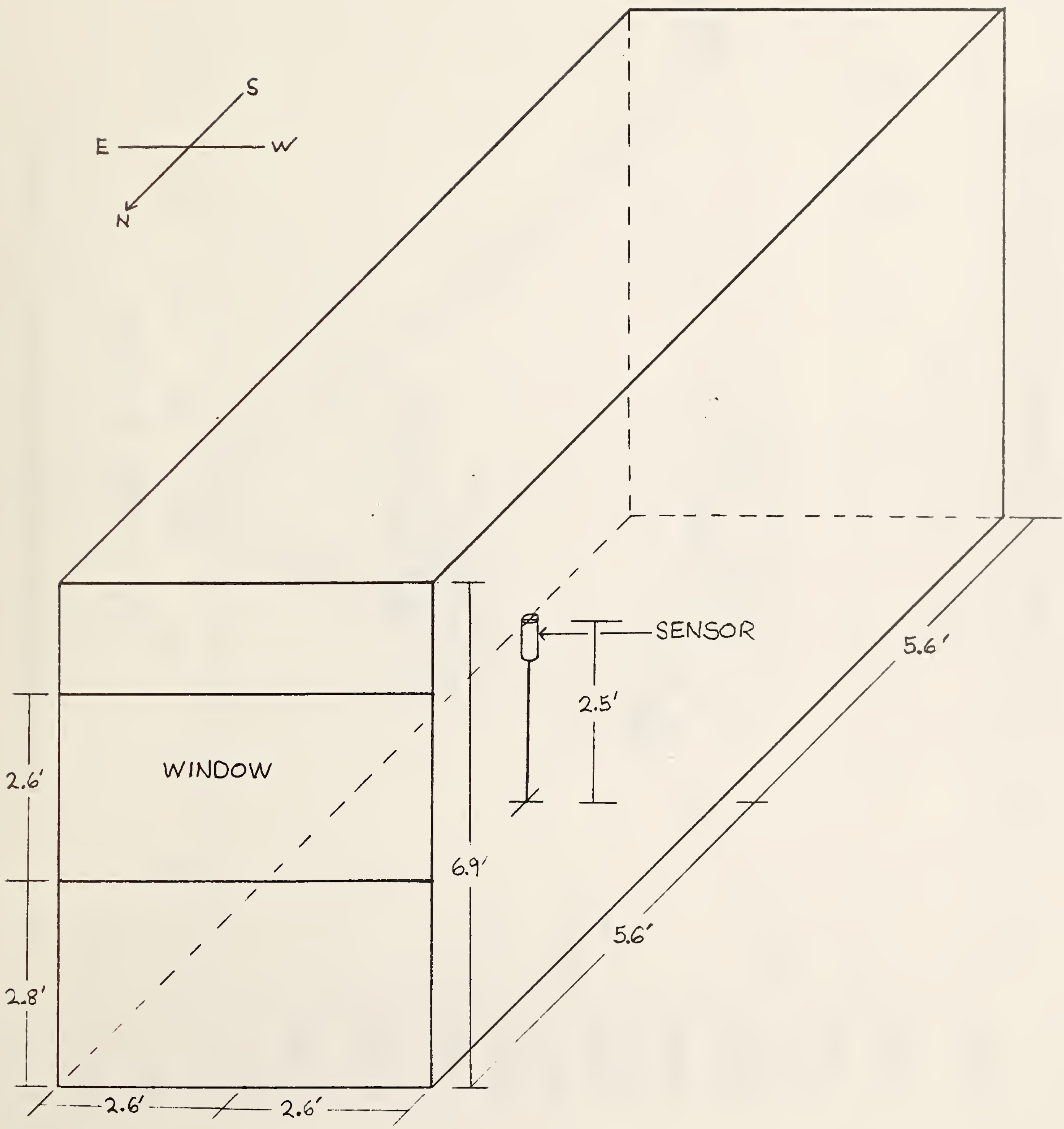

Figure 1. Layout of Test Room

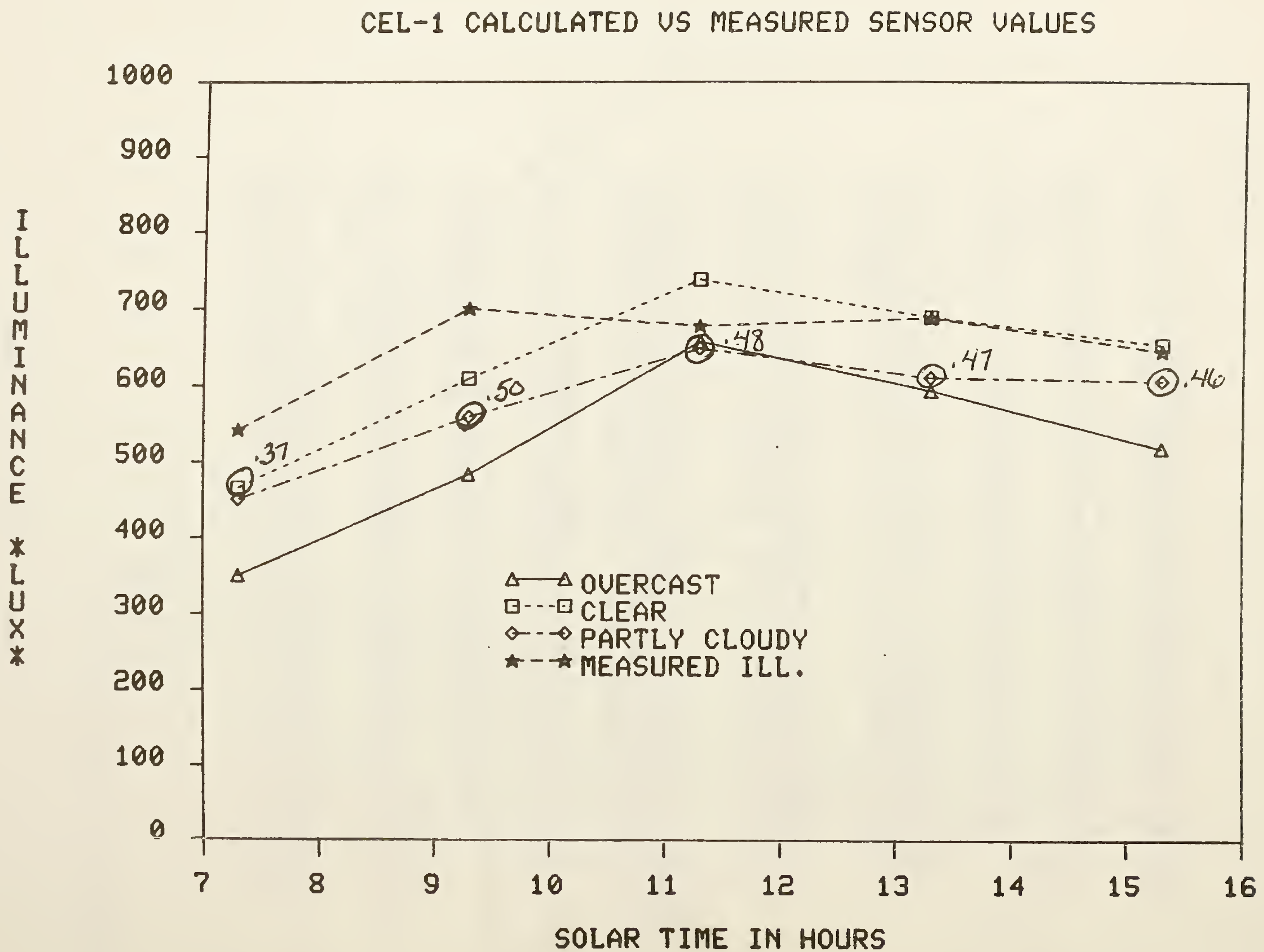

Figure 2. Graph of CEL-1 Results vs Measured Data for Julian Date 91

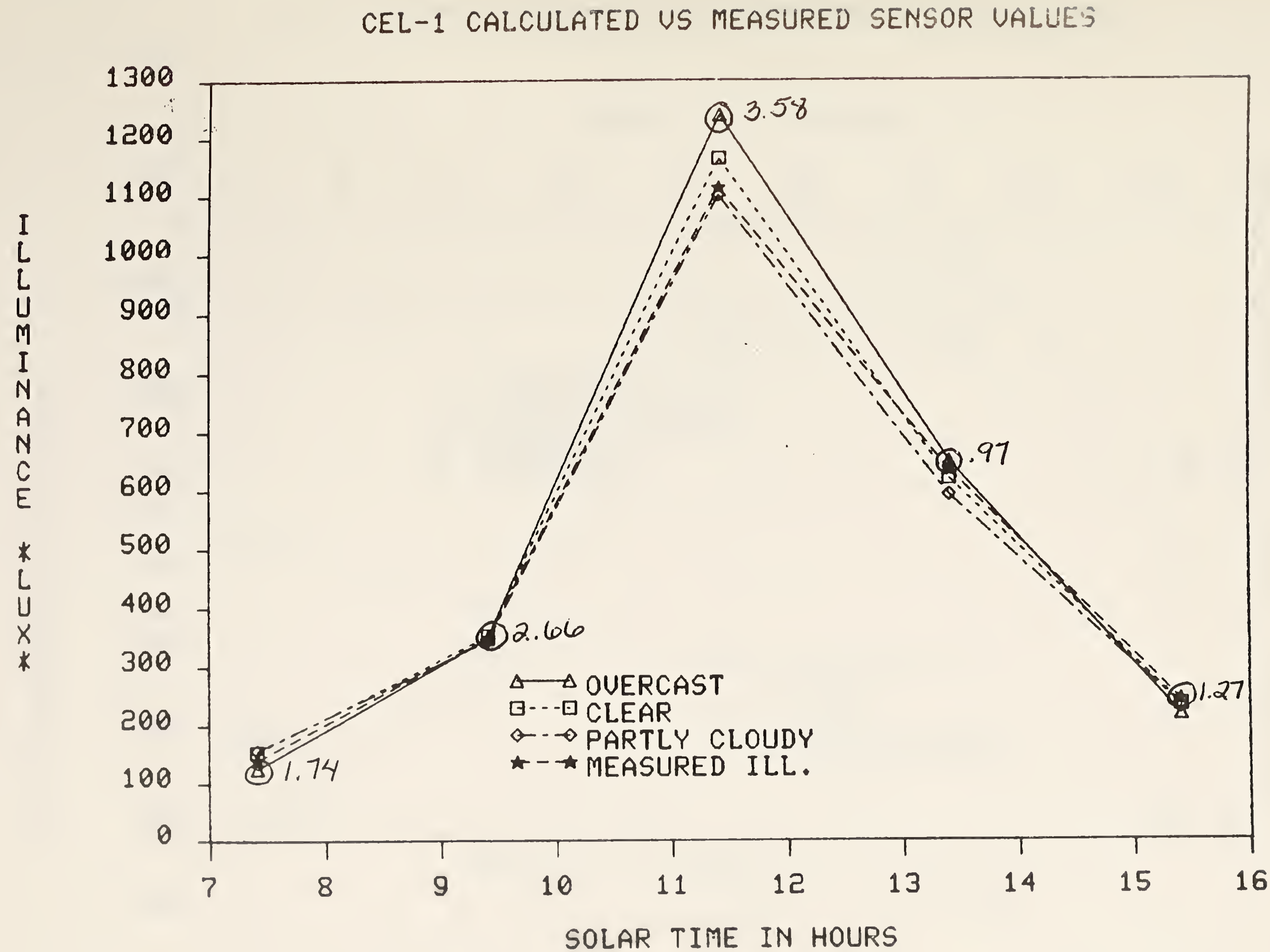

Figure 3. Graph of CEL-1 Results vs Measured Data for Julian Date 149

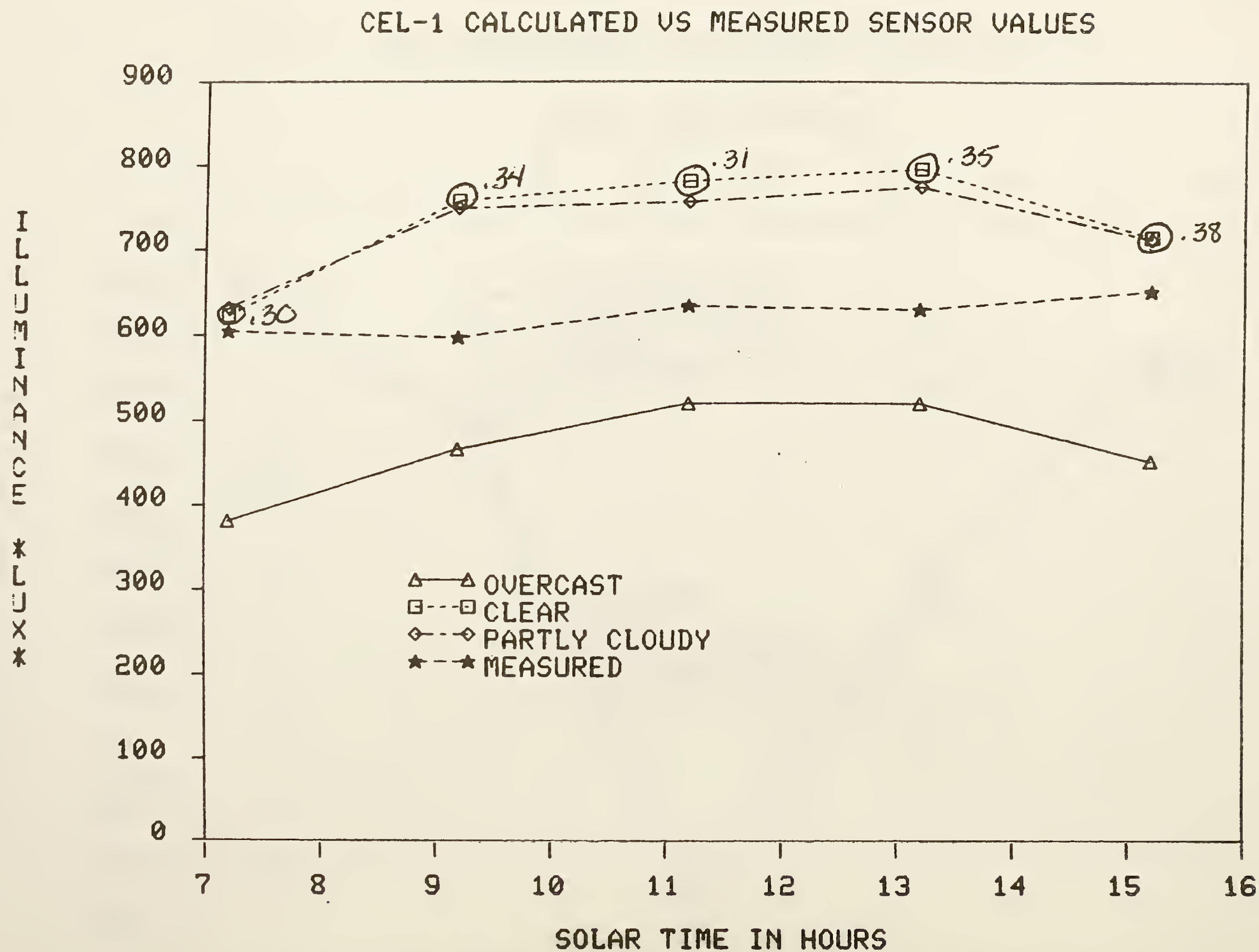

Figure 4. Graph of CEL-1 Results vs Measured Data for Julian Date 189

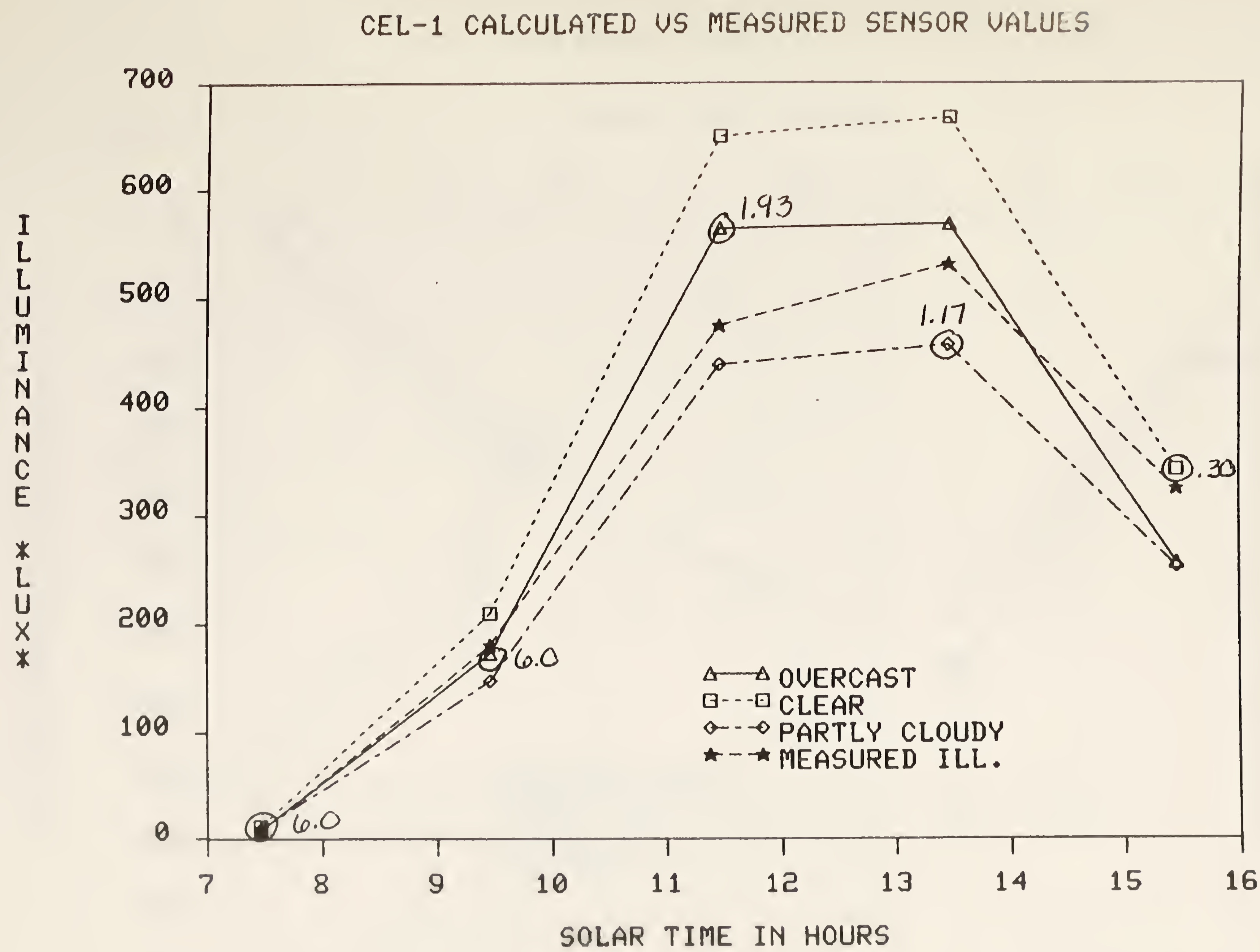

Figure 5. Graph of CEL-1 Results vs Measured Data for Julian Date 349

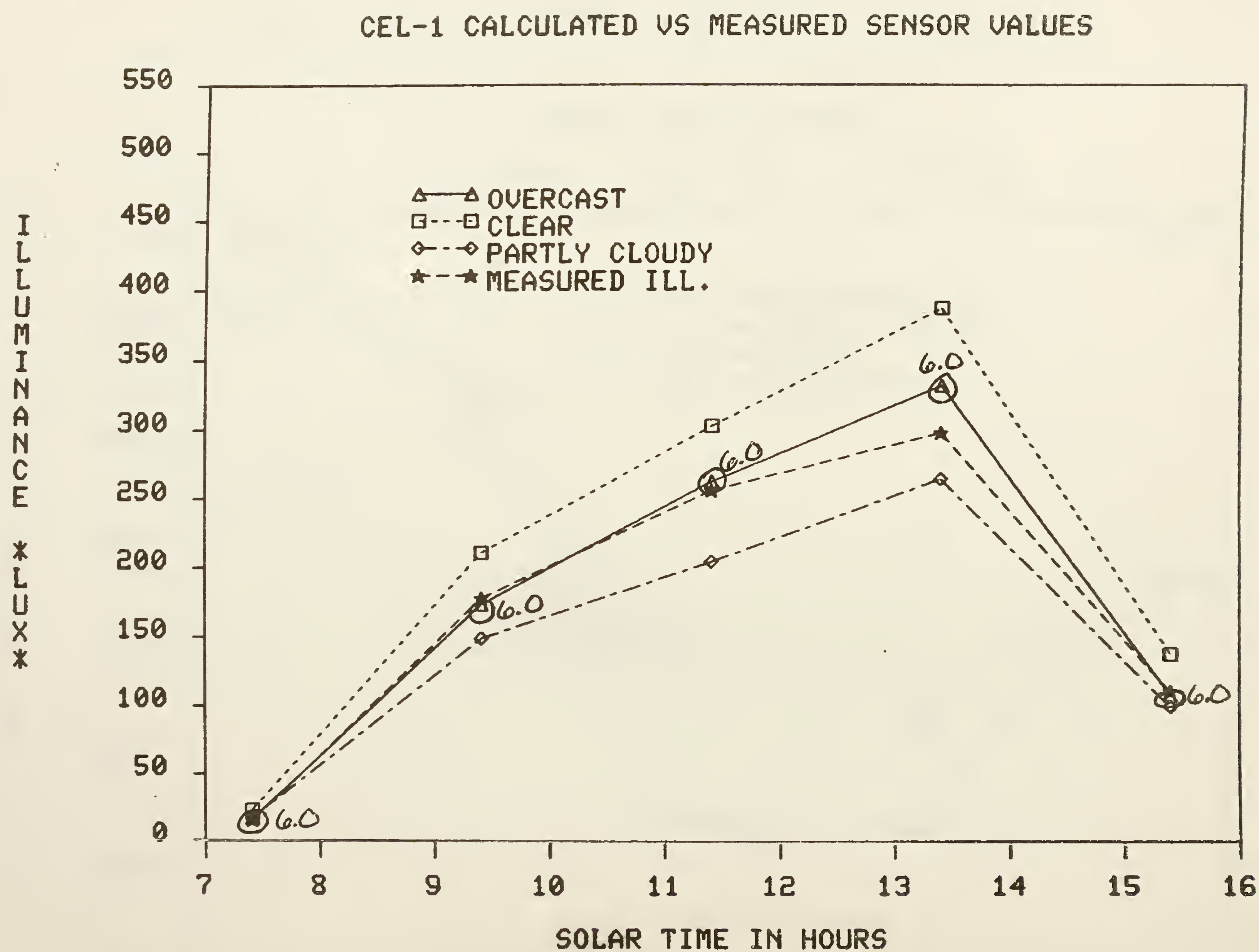

Figure 6. Graph of CEL-1 Results vs Measured Data for Julian Date 355

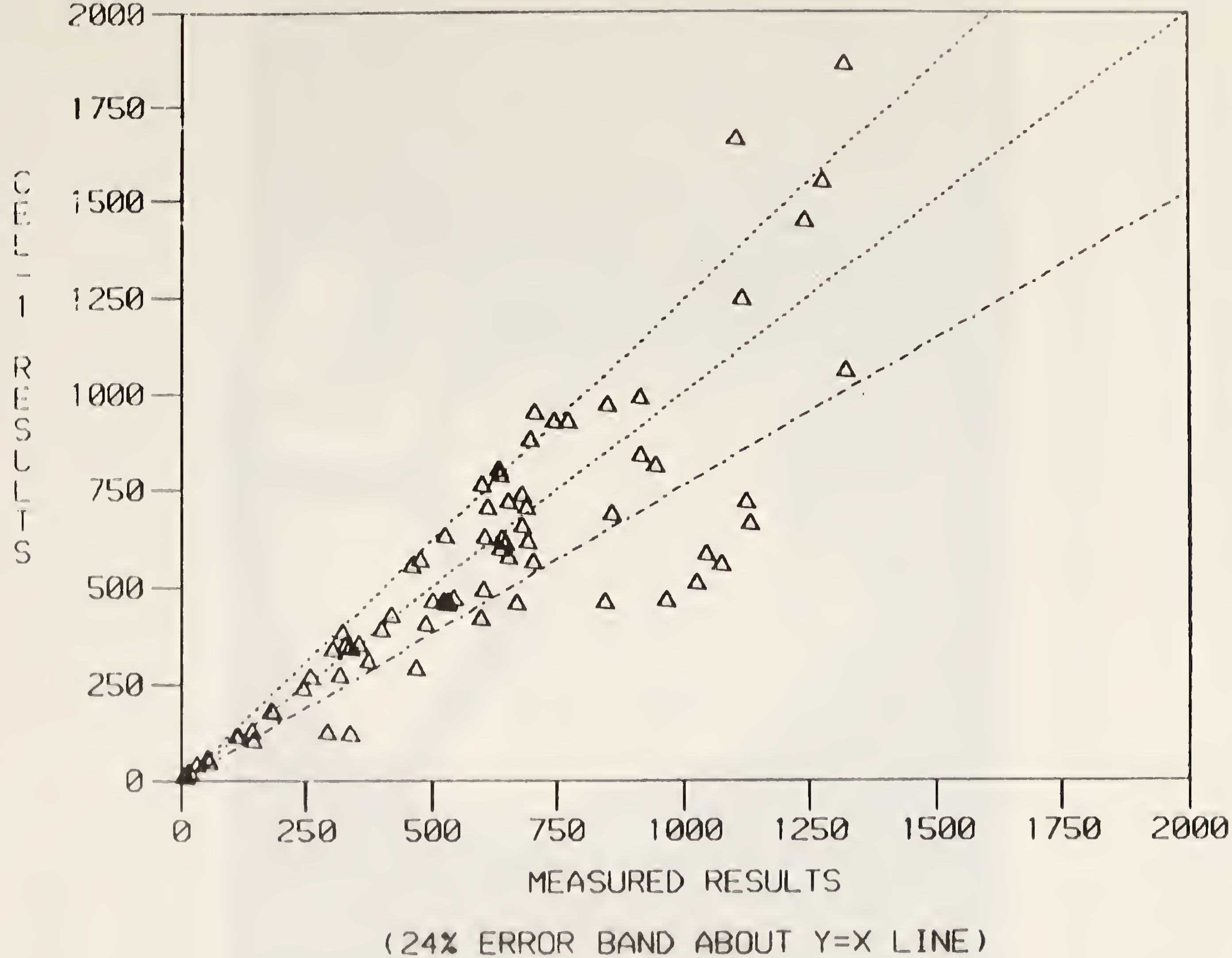

Figure 7. Scatter Plot of Measured Data vs CEL-1 Calculated Results

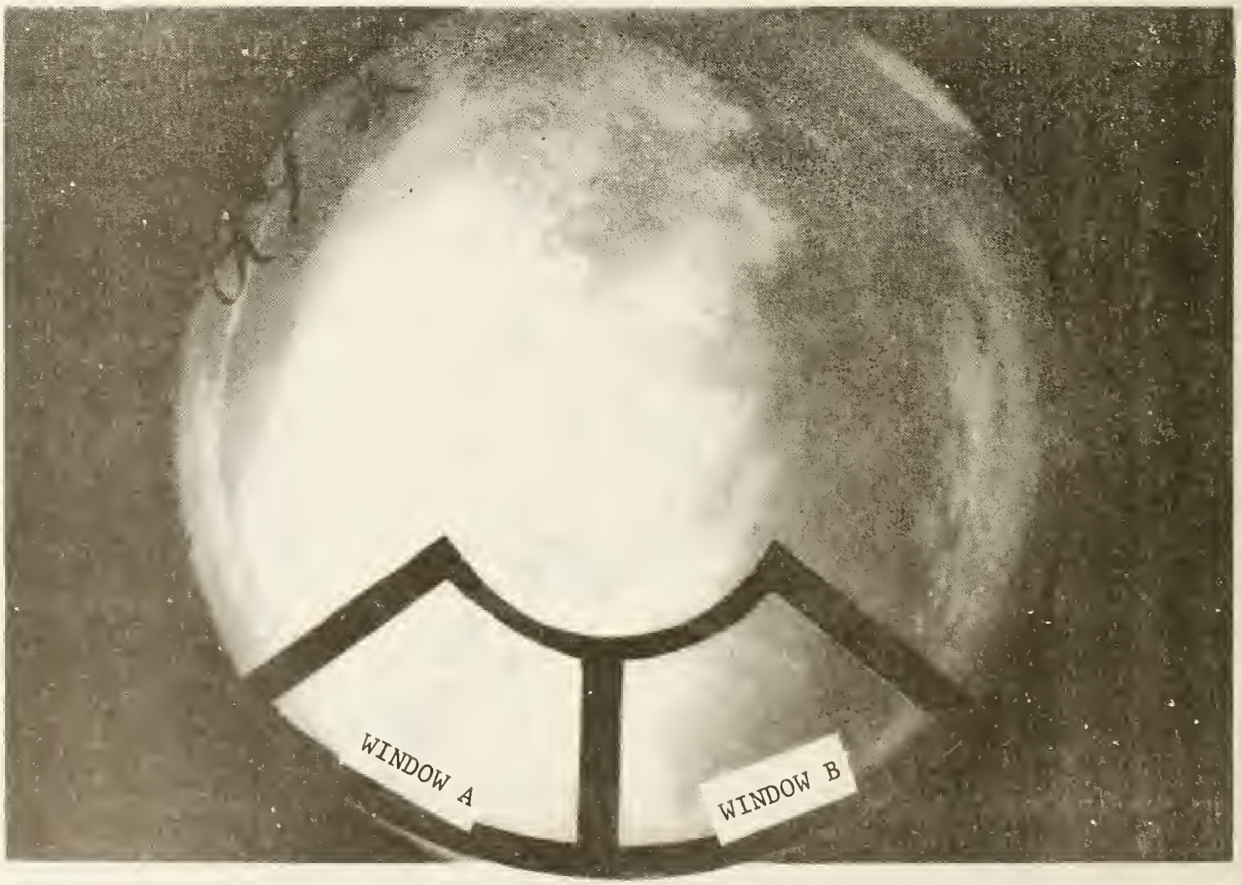

Figure 8. Effect of Sky Luminance Variations on Interior Illumination

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U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2937	2. Performing Organ. Report No.	3. Publication Date

4. TITLE AND SUBTITLE

Validation of Daylight Prediction With CEL-1

5. AUTHOR(S)

Steve Treado, Cindy Francisco and Douglas Holland

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Calculations of interior illuminance levels using the CEL-1 computer program are compared to measurements, for a typical office space. The comparisons are made for a wide range of sky conditions, solar intensities and seasonal intervals using a north facing window. The statistical uncertainty associated with the interior daylight calculations is examined and the sources of the uncertainty are discussed. The results show that for all sky types, the interior illuminance calculations have an uncertainty of +/-24%, with the major uncertainties being due to unique and unpredictable sky luminance distributions and difficulty in determining the appropriate sky condition from standard weather data.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

building energy, daylight, illuminance, fenestration, solar radiation, window

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☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

23

15. Price

$7.00